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AN EVALUATION OF THE RELATIVE PERFORMANCE OF THREE INFRARED IMAGERS THROUGH FOG

June 1, 1982

AUTHOR: E. H. HACKNEY

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Early in 1980, a field test of three thermal imaging sensors was performed. During these tests, a Honeywell scanning imager in the 8-12μm band demonstrated superior performance at short range over the other sensors and Schottky barrier staring array sensor in the 3μm band demonstrated superior performance at long range. Insufficient data was available for a complete evaluation; however, a qualitative analysis was performed.

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As a result of the analysis, it was concluded that the 8-12 µm scanning imager had higher sensitivity and resolution than the other two sensors, and therefore showed superior short range performance. The most probable reason for the superior performance of the Schottky barrier 3-5 µm sensor at long range was reduced atmospheric attenuation in the 3-5 µm band. Atmospheric transmission in the 3-5 µm band is often lower than that in the 8-12 µm band, especially in a very humid atmosphere as was the case during the tests.

ABSTRACT

Early in 1980, a field test of three thermal imaging sensors was performed. During these tests, a Honeywell scanning imager in the 8-12 μm band demonstrated superior performance at short range over the other sensors and Schottky barrier staring array sensor in the 3-5μm band demonstrated superior performance at long range. Insufficient data was available for a complete evaluation; however, a qualitative analysis was performed.

As a result of the analysis, it was concluded that the 8-12μm scanning imager had higher sensitivity and resolution than the other two sensors, and therefore showed superior short range performance. The most probable reason for the superior performance of the Schottky barrier 3-5 μm sensor at long range was reduced atmospheric attenuation in the 3-5 μm band. Atmospheric transmission in the 3-5 μm band is often lower than that in the 8-12μm band, especially in a very humid atmosphere as was the case during the tests.

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CHAPTER I
INTRODUCTION

Early in 1980, a brief field test of three infrared imaging sensors was made at Wright-Patterson Air Force Base. The three imaging systems or FLIRS (forward looking IR) were: (1) a 3-5 μm RCA staring system using a Schottky barrier (PtSi array), (2) a 3-5μm AGA scanning system, and (3) a 8-12μm Honeywell scanning system. The weather during the test was foggy with intermittent very light rain. The qualitative assessment of the results, indicated the 8-12μm system was more sensitive than either of the 3-5μm systems at short range. The 3-5μm staring system performed better than the 3-5μm scanning system at short range and performed better than either scanning system at long range. The purpose of this task was to evaluate and explain these results.

No measurements were made during the test and no data on the imaging systems is available, so the conclusions drawn here are only qualitative. However, the observed result can be explained with some confidence based on the little data available, and on generic FLIR performance and atmospheric transmission in the 3-5μm and 8-12μm infrared transmission bands. In the following sections, infrared imaging is first discussed in general terms, then generic FLIR performance and atmospheric effects are discussed in more detail. In the final section, the results are summarized and conclusions are presented.

CHAPTER II
BACKGROUND

The performance of a thermal imaging system is a function of the characteristics and parameters of the imaging system, the characteristics of the observed scene, and the nature of the intervening atmosphere. One of the more important variables in the design of an infrared imaging system is the operational spectral band. The spectral band affects the sensitivity of the system itself, the effect of the atmosphere on the overall system performance and, in some cases, the response of the system to a given observed scene.

For ideal background limited systems and zero atmospheric attenuation, a system operating in the 8-12 μm band can be shown to be more sensitive than one in the 3-5 μm band. (See chapter IV for a detailed discussion.) Additionally, near ideal detector performance is easier to achieve in the 8-12 μm band than in the 3-5 μm band. Therefore, most thermal imaging systems (for near ambient target and background temperature) are designed for the 8-12 μm band. This is especially true for systems designed for short range.

As the operational range for a system is increased, atmospheric attenuation becomes increasingly important. Atmospheric attentuation is usually greater in the 8-12 μm band than in the 3-5 μm band, and increases as the content of water vapor in the atmosphere rises. For long range infrared systems, therefore, the 3-5 μm band is often chosen.

In most cases, infrared scenes are assumed to be composed of black bodies or "gray" bodies, and the wavelength effects are already accounted for in the analysis of the FLIR performance. The most notable exception is in ERSAT data, where the earth is viewed in a large number of narrow spectral bands. In ERSAT data the detailed spectral radiation of plants and/or minerals can be used for identification, and in the case of plants, for measurement of growth and health. For most imaging systems, these detailed spectral effects are ignored.

A. THE EXPERIMENT

The experiment under evaluation was performed at Wright-Patterson Air Force Base in early 1980. During the experiment, three thermal imaging systems were located side by side on a tower approximately 100 feet above the ground. Two scanning systems (a 3-5μm AGA imager and a 8-12μm Honeywell imager) and one staring system (a 3-5μm RCA imager) were employed. The AGA imager is a commercial quality system designed primarily for industrial applications. The Honeywell imager is assumed to be a reasonably high quality military system. The RCA staring imager is a developmental system employing a 25 x 50 mosaic detector of PtSi (Schottky barrier technology). Otherwise, very little is known about the systems.

The scope of the test was limited and consisted essentially of a qualitative performance comparison based on assessments by the observers of the displayed image quality. The weather condition during the test was heavy fog with very light rain. At short range, the performance of the 8-12μm Honeywell system was clearly superior to that of both 3-5μm systems, and the performance of the 3-5μm RCA staring system was somewhat better than the 3-5μm AGA scanning system. At long range, the 3-5μm RCA system was superior to both scanning systems. The horizon line and cloud structure were observable through the fog with the 3-5μm RCA system. These features were not observable with the other two systems. An evaluation and analyses of these test results are presented in the following sections.

CHAPTER III
GENERIC THERMAL IMAGER PERFORMANCE

A. RADIOMETRIC EFFECTS

A warm body radiates electromagnetic energy as a function of its temperature and its emissivity (radiation relative to the radiation of an ideal blackbody at the same temperature). A blackbody radiation curve for 300°k (80.6°F) is shown in figure III-1. An infrared detection system operates by sensing radiation which lies in the infrared spectral band (approximately .7μm to 30μm in wavelength). Most infrared sensors, however, operate in the near infrared band (near 1μm), or in one of the two atmospheric "windows" (3-5μm and 8-12μm). Except for space applications, the objects in a given scene are near the same temperature and emissivity; therefore, the sensors are designed to display variation in emitted radiation over the scene rather than absolute energy. A system's sensitivity is characterized in terms of its ability to sense temperature difference. One important parameter in defining the performance of an infrared system is noise equivalent temperature difference (NETD). NETD is the temperature difference for large scene objects which yield a signal-to-noise ratio of 1 at the system output. The lower the NETD, the more sensitive the system.

It can be shown that the NETD for a thermal imager is proportional to the reciprocal of D* and N_T, i.e.

$$\mathrm{NETD} \propto \frac{1}{D^* N_T} \qquad \text{Eq. (1)}$$

D* is a detector sensitivity parameter and N_T is the change in black body radiance with temperature.

In an ideal infrared system, the system noise level is determined only by the random arrival of photons from the observed scene. For this background limited (BLIP) case, the D* ~~ɔ~~ determined only by the

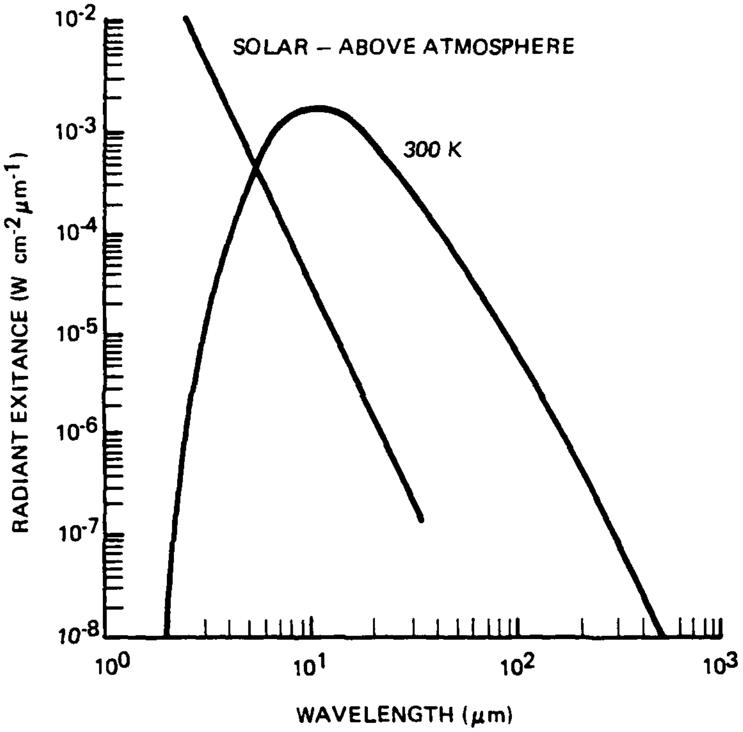


Figure III-1. Radiance for 300^{0}K Blackbody and Reflected Sunlight background temperature. It can be shown that for two well designed systems, one in the 3-5μm band, and one in the 8-12μm band, which are otherwise identical, the 8-12μm system will have a better (lower) NETD. For a 300°k target this is not surprising since, 8-12μm straddles the peak of the 300°k black body curve (see figure III-1). Depending on the exact wavelength bands of the two systems, the 8-12μm system can be as much as five times as sensitive as the 3-5μm system. Furthermore, 8-12μm detectors are generally closer to BLIP limit than 3-5μm detectors. Without knowing the system parameters for the three systems, it is not surprising that the 8-12μm system is more sensitive than the 3-5μm systems at close range.

For the reasons discussed above, the 8-12μm band is often selected for operational infrared systems, especially systems designed for near ambient target temperatures and shorter ranges. The effects of atmospheric transmission have been ignored thus far, but will be addressd in the next section, since longer operating ranges and the effects of atmospheric attenuation on operational wavelength can far outweigh the previously discussed effects.

Another factor to consider is the effects of solar radiation on the imaging systems. The solar irradiance curve (figure III-1) shows that the sun contributes much more in the 3-5μm band than in the 8-12μm band. In 8-12μm imagery, the effects of reflected sunlight can be neglected. In the 3-5μm band, however, solar reflection can contribute significnatly to the imagery, and therefore reflected sunlight could have considerably enhanced the observability of cloud structure with the 3-5μm sensor.

B. IMAGER TYPES

Several types of thermal imaging systems are in common use. In the subject experiment, a staring or mosaic sensor (the Schottky array sensor) and two lines or raster scanning sensors (the AGA and the Honeywell sensors) were employed.

A mosiac sensor is illustrated in figure III-2. Using this sensor, the scene is imaged on a focal plane detector array and each detector element stares at a fixed point in the field of view. Most mosaic sensors (the Schottky device, for example) detect the absolute scene irradiance.

A raster scanning sensor optomechanically scans the scene across single or small numbers of detectors in a fashion similar to a conventional TV, i.e., horizontally across each line then stepped down line by line as illustrated in figure III-3. In raster scanning systems, the detector outputs are AC coupled, i.e., they respond to variations in the scene irradiance. Due to the AC coupling in many raster scanning systems, the average output of each line is a fixed grey level. As a result, vertical artifacts in the scene will often result, i.e., errors in the vertical structure of some objects. The most notable artifact is the loss of the horizon line, i.e., the image is the same brightness below the horizon as above. There is a technique called "DC restoration" which can be incorporated to correct the average grey level of each line. If the Honeywell imager did not employ DC restoration, the above effect could account for the lack of a horizon line in the long range 8-12μm imagery. The effect, however, would not explain the lack of cloud structure, which was visible in the 3-5μm Schottky system.

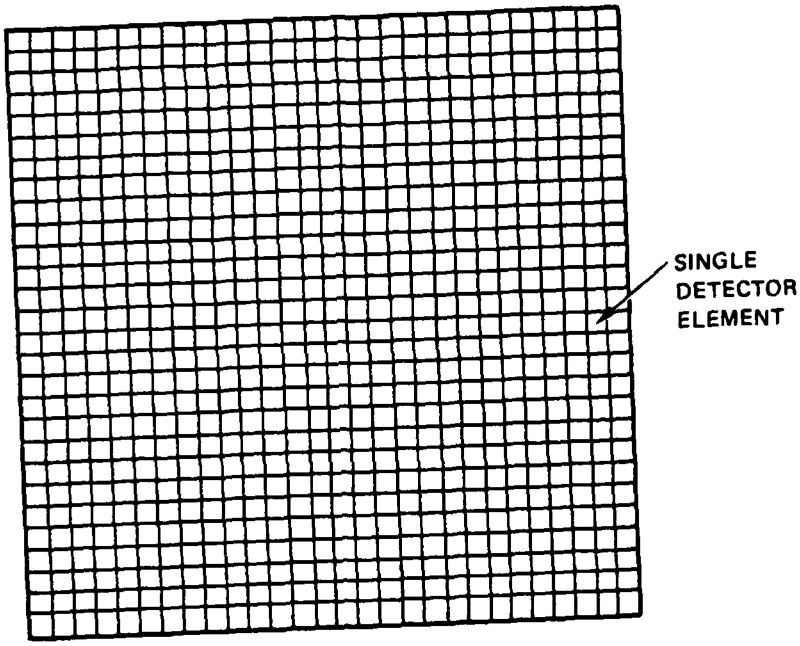


Figure III-2. Image Sampling for Mosaic Sensor

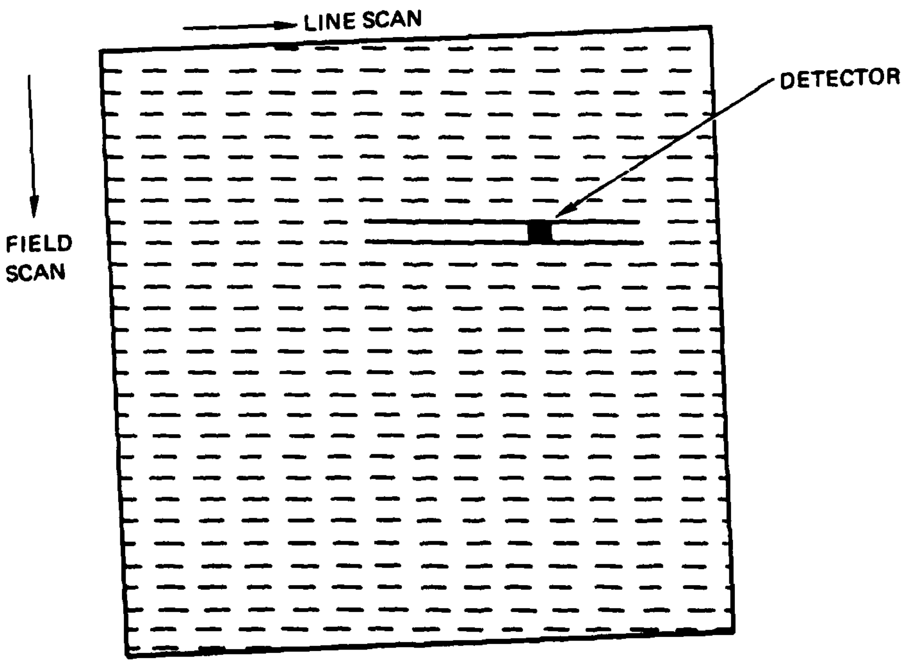


Figure III-3. Image Sampling for Raster Scanning Sensors

CHAPTER IV
ATMOSPHERIC ATTENTUATION

The propagation of infrared radiation through the atmosphere is a very complex topic. Figure IV-1 shows a plot of atmospheric transmission versus wavelength for a given set of atmospheric conditions. The transmission varies rapidly with small changes in wavelength. In figure IV-2, which has higher resolution and is for water only, the effects of transmission variation with wavelength is even more pronounced. In addition, the transmission varies considerably with variation in the composition of the atmosphere (vapor and particulate H_2O, CO_2, O_3, N_2O,, haze, dust, etc.). There is no region of the infrared spectrum which does not suffer from some atmospheric attenuation.

One of the most important and variable attenuators of infrared radiation is water. At sea level, the proportion of CO_2, O_3, and N_2O is relatively constant, whereas the humidity can go from zero to saturation. Water attenuates more in the 8-12μm band than in the 3-5μm band. Therefore, when the sensor to target path contains an appreciable amount of water, there is generally greater atmospheric transmission in the 3-5μm band than in the 8-12μm band.

Insufficient data was taken to calculate the atmospheric transmission during the test period. It is felt, however, that the reason for the improved performance of the 3-5μm imager with respect to the 8-12μm imager at long range was lower attenuation in the 3-5μm band. Figure IV-3 illustrates this effect for a particular pair of sensors (one 3.4-5.1μm and one 8.1-12.2μm) and a particular set of atmospheric conditions (not necessarily similar to those during the subject experiment). For the case illustrated in the figure, the 8.1-12.2μm sensor is more sensitive and has a higher signal-to-noise ratio at short range. As the range increases, the signal-to-noise ratio of the 8.1-12.2μm sensor decreased faster than that of the 3.4-5.1μm sensor. At ranges greater than 6.5km, the signal-to-noise ratio of the 3.4-5.1μm sensor is higher than that of the 8.1-12.2μm sensor. Figure IV-3 clearly illustrates qualitatively the conditions during the imager comparison tests.

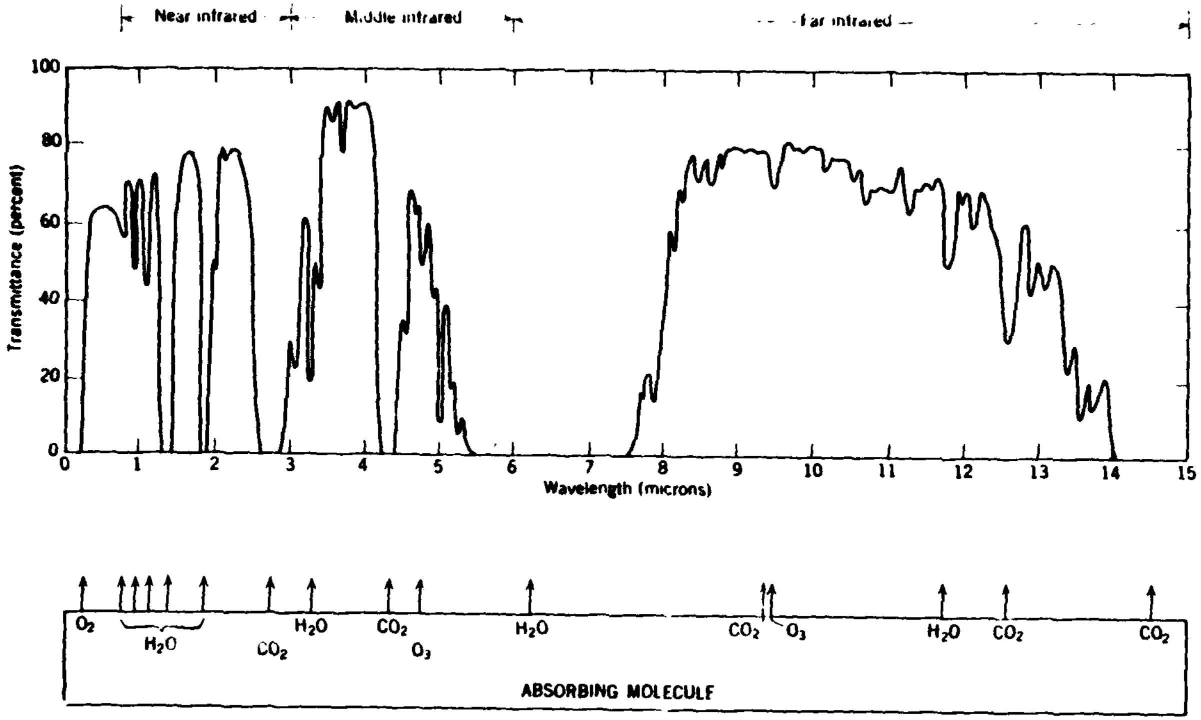
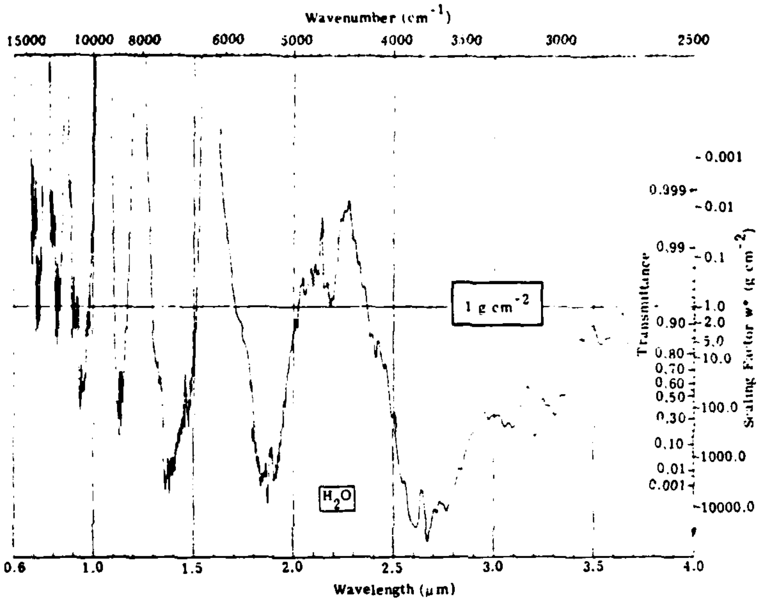
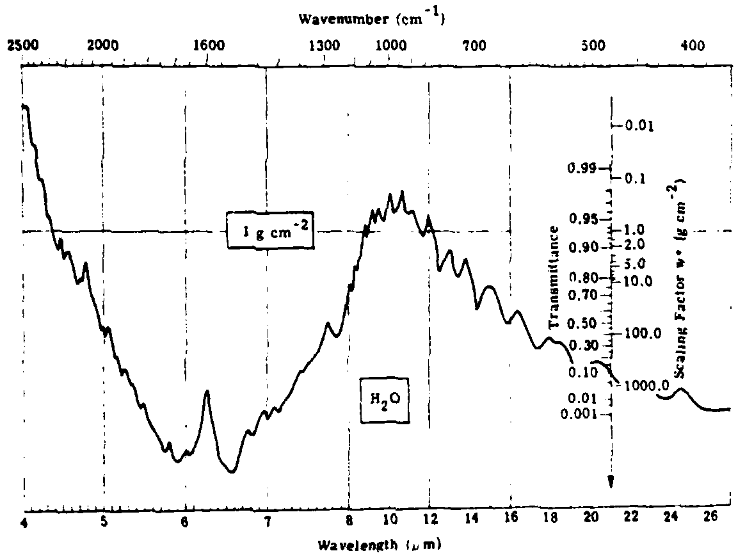


Figure IV-1. Transmittance of the Atmosphere for a 6000 ft Horizontal Path at Sea Level Containing 17mm of Perceptible Water (Adapted from Gebbie et. al. {1}).



(a) Transmittance of water vapor (0.6 to 4.0 μm).



(*b*) Transmittance of water vapor (4.0 to 26.0 μm).

Figure IV-2. Infrared Transmission of Water Vapor Versus Wavelength

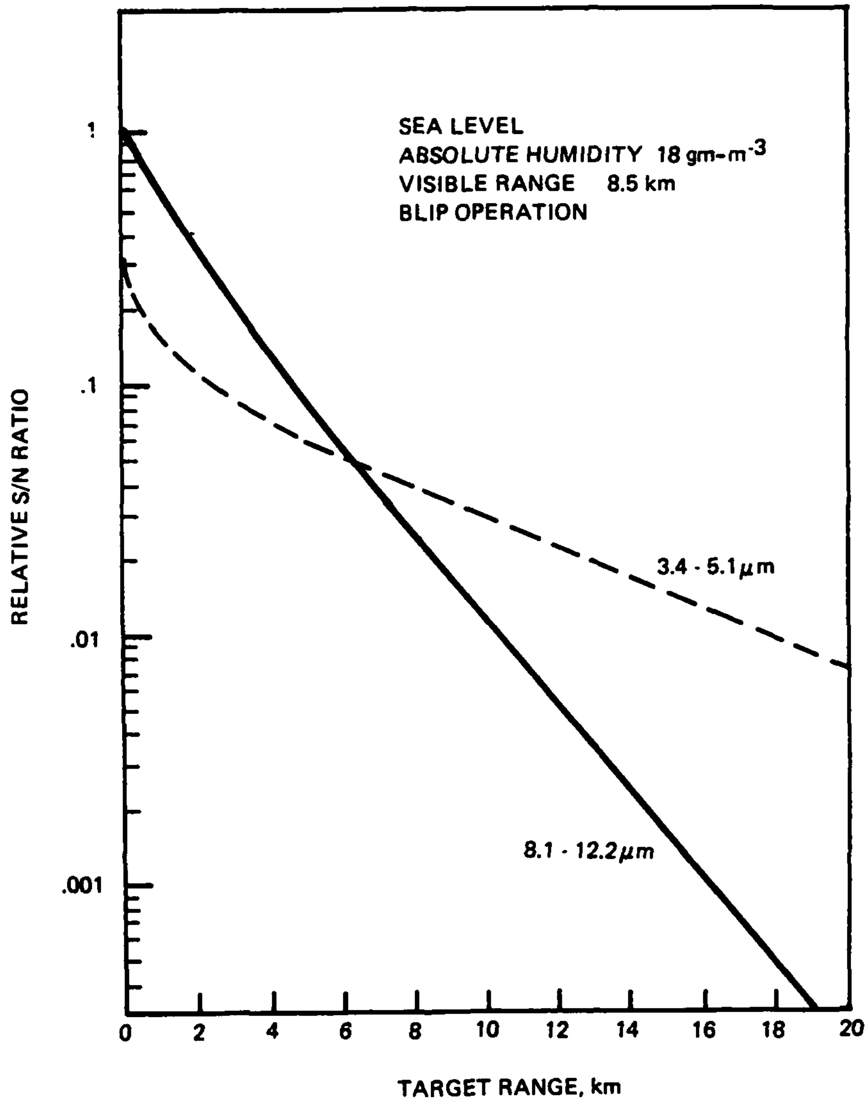


Figure IV-3. Relative Signal to Noise Versus Range for a 8.1 - 12.2 μm Sensor and a 3.4 - 5.1 μm Sensor in a Given Atmosphere

CHAPTER V
CONCLUSIONS

A qualitative analysis of the results and conditions of the experiment has been presented in the previous pages. Due to the lack of data on the sensors employed during the experiment, additional quantitative analysis cannot be performed. Based on these analyses, the following explanation of the most probable causes of the experimental result is presented in likely order of importance.

(1) The Honeywell 8-12μm sensor is probably a high performance system with both greater sensitivity and resolution than either of the 3-5μm devices. As a result, it demonstrated significantly better imagery at short ranges.

(2) The Schottky barrier PtSi array was probably more sensitive than the AGA system and therefore performed better than the AGA sensor in all cases.

(3) Due to the high atmospheric water content, it is believed that there was more atmospheric attenuation in the 8-12μm band than the 3-5μm band during long range testing. This would explain the superior long range performance of the Schottky barrier system (3-5μm) over the Honeywell system (8-12μm).

(4) Since the contribution from sunlight is much more pronounced in the 3-5μm band than the 8-12μm band, solar irradiance could have enhanced the visibility of cloud structure in the 3-5μm band.

(5) If DC restoration was not employed in the Honeywell sensor, the lack of the horizon in the Honeywell imagery could have been an antifact of line scanning.

CHAPTER VI
RECOMMENDATIONS

In anticipation of further system comparisons similar to the ones discussed here, the following recommendations are made:

A. PRIOR TO TESTING

(1) Formulate a test plan and test procedures.

(2) Measure the performance of all systems. The measurements should include noise equivalent temperature (NET), minimum resolvable temperature versus spatial frequency (MRT), and modulation transfer function (MTF).

B. DURING TESTING

(1) Measure atmospheric condition, i.e., temperature and relative humidity.

(2) Estimate range of visibility.

(3) Employ standard targets of known infrared characteristics at several ranges.

(4) Perform experiments at several ranges and under several different atmospheric conditions.

(5) Keep detailed records of the test conditions and test results, including qualitative observations.

(6) Record the video of imagery for all sensors.

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